nation would result in increased efficiency of seed utilization. Treatment with GA_{4+7} stimulates 42-day germination at 30°/20°C (86°/68°F) but not at the cooler temperatures [20°/10°C (68°/50°F)] similar to those encountered by commercial growers under field conditions. Thus, treatment of seeds with GA_{4+7} appears to have merit primarily for greenhouse production of seedlings.

Literature Cited

1. Adkins, C.R. 1983. Effects of selected fungicides, surface sterilants, and environmental factors on germination of Fraser fir seed. M.S. Thesis, N.C. State Univ., Raleigh.

2. Adkins, C.R., L.E. Hinesley and F.A. Blazich. 1984. Role of stratification, temperature, and light in Fraser fir germination. Can. J. For. Res. 14:88–93.

3. Ballington, J.R., G.J. Galleta and D.M. Pharr. 1976. Gibberellin effects on rabbiteye blueberry seed germination. HortScience 11:410–411.

4. Blazich, F.A. and L.E. Hinesley. 1980. Effect of temperature and light on Fraser fir seed germination. Proc. Southern Nurserymen's Assoc. Res. Conf., 25th Annu. Rpt. p. 225–227.

5. Bretzloff, L.V. and N.E. Pellett. 1979. Effect of stratification and gibberellic acid on the germination of *Carpinus caroliniana* Walt. HortScience 14:621–622.

6. Dorn, C.M. and K.W. Mudge. 1985. Vacuum infiltration of gibberellic acid stimulates germination of dormant black walnut seeds. J. Environ. Hort. 3:172–175.

7. Franklin, J.F. 1974. *Abies*. Mill. Fir, p. 168–183. *In*: C.S. Schopmeyer (Tech. Coordinator). Seeds of Woody Plants in the United States. Agri. Handbook 450. U.S. Dept. Agr. For. Serv., Washington, D.C.

8. Hartmann, H.T. and D.E. Kester. 1983. Plant Propagation, Principles and Practices. 4th ed. Prentice-Hall, Englewood Cliffs, N.J.

9. Korvacs, J. and J. Voros. 1961. Forestry research with gibberellin. Erdo 10:199–202.

10. Liu, T.S. 1971. A monograph of the genus *Abies*. National Taiwan Univ., Taipei, Taiwan (Republic of China).

11. Pharis, R.P. and C.G. Kuo. 1977. Physiology of gibberellins in conifers. Can. J. For. Res. 7:299–325.

12. Richardson, S.D. 1959. Germination of Douglas-fir seeds as affected by light, temperature, and gibberellic acid. For. Sci. 5:174–181.

Irrigation Frequency and Shading Influences on Water Relations and Growth of Container-Grown *Euonymus japonica* 'Aureo-marginata'[1]

S.E. Newman and M.W. Follett[2]

Department of Horticulture

Mississippi Agricultural and Forestry Experiment Station

P.O. Drawer T

Mississippi State, MS 39762

Abstract

Trickle irrigation frequency, shading, water relations, and plant growth of container-grown *Euonymus japonica* Thunb. 'Aureo-marginata' was investigated. Plants were grown under a combination of 3 irrigation frequencies and 2 shade levels. Stomatal conductance (g_s) was reduced when plants were irrigated 3 times per week compared to irrigation daily and twice daily after week 4 under full sun and after week 8 under shade. Few differences were detected in predawn shoot water potential (Ψ_{shoot}) under shade at any irrigation level. The predawn shoot water potential (Ψ_{shoot}) was reduced (more negative) for plants irrigated 3 times per week compared to irrigation daily and twice daily after week 8 for plants grown under full sun and week 10 for plants grown under shade. These values remained lower for the duration of the study. Plants grown under shade and irrigated once daily had greater plant dry weight and leaf area compared to plants irrigated either twice daily or 3 times per week. They were also larger than all plants grown under full sun. Plants grown under shade had greater chlorophyll levels per unit leaf area. Under shade, plant quality was not affected by irrigation rates. However, only plants grown under shade were of salable quality.

Index words: water potential, stomatal conductance, environmental stress

Introduction

Many woody landscape species are almost entirely produced in containers. Most growers use soilless mixes that require a consistent source of nutrients appropriately balanced and careful water management. Many container-grown woody species require shading and additional irrigation during the summer months when the afternoon temperatures exceed 35°C (95°F) (4). Elevated root-zone temperatures are also a problem. The root-zone in exposed containers can reach temperatures as high as 50°C (122°F) (6, 8, 9, 14). Therefore, species with especially sensitive root systems must be produced under shade or the root-zones must be protected until the plant canopy provides shade (6, 8). Plants produced under shade require modifications in management

[1]Received for publication February 15, 1988, in revised form June 13, 1988. Mississippi Agricultural and Forestry Experiment Station Journal Series 6715. The authors thank Flowerwood Nursery, Inc., Mobile, Alabama for plant material and Mr. F.K. Wages for technical assistance.

[2]Assistant professor and research assistant, resp.

systems, especially irrigation. Excess irrigation may increase the plants susceptibility to root pathogens, decrease oxygen in the media, or increase water uptake leading to oedema. Oedema, a corky growth on epidermal cells, is a physiological disorder often observed by many growers in the south producing *E. japonica* cultivars under shade.

Euonymus japonica 'Aureo-marginata', a popular landscape shrub for southern landscapes, is a species that is generally produced under moderate shade for the best plant growth by southern growers. Excess irrigation under shade or inadequate irrigation under full sun during periods of high mid-day temperatures and high humidities often leads to decline of *E. japonica* cultivars under container conditions (13).

An understanding of how irrigation frequency and shade interact to influence the water relations and ultimately plant growth of *E. japonica* will give the grower the ability to produce a higher quality crop. The objective of this investigation was to compare the effects of irrigation frequency and shading on stomatal conductance, transpiration, shoot water potential, and plant growth of *Euonymus japonica* 'Aureo-marginata'.

Materials and Methods

Liners of *Euonymus japonica* 'Aureo-marginata' were potted on February 10, 1986 into 3.8 L (#1) polyethylene containers filled with 4:1 composted pine bark and sand (v/v) medium amended with 2.95 $kg \cdot m^{-3}$ (5 lbs/yd^3) dolomitic limestone, 2.95 $kg \cdot m^{-3}$ (5 lbs/yd^3) gypsum, 1.18 $kg \cdot m^{-3}$ (2 lbs/yd^3) treble super phosphate, 74 $g \cdot m^{-3}$ (2 oz/yd^3) fritted trace elements (W.R. Grace and Co., Fogelsville, PA), and 4.72 $kg \cdot m^{-3}$ (8 lbs/yd^3) 18N-2.4P-9.6K (18-6-12) slow release fertilizer (Osmocote, Sierra Chemical Co., Milpitas, CA). The plants were placed in a glasshouse maintained at 20°C $\pm$2° (68°F $\pm$4°) for 6 weeks and moved to the production area on April 28, 1986. Irrigation treatments were begun on May 16, 1986.

The production area was covered with a quonset-style pipe frame, 11 $\times$ 30 m (36 $\times$ 98 ft) with the length oriented north and south. The north half of the frame was covered with 53% polypropylene shade cloth and the south half was left uncovered. Irrigation header pipes were arranged in 6 rows, oriented north and south 1 m (3.3 ft) apart, in each half of the frame. The trickle irrigation frequency rates, once daily, twice daily, and 3 times per week were randomly assigned to 2 headers each for both the shade and full sun treatments. The individual headers had 14 plants spaced on 1 m (3.3 ft) centers to avoid mutual shading, each with an individual irrigation leader.

The irrigation frequencies were controlled with an electronic clock and solenoid valves. The irrigation times were 0600 CST daily for the once daily irrigation, 0600 and 1800 CST daily for the twice daily irrigation, and 0600 CST on Tuesday, Thursday, and Saturday for the 3 times per week irrigation. Each irrigation cycle was 5 min resulting in approximately 2 L (0.53 gal) of water being applied to each container (>10% excess total pore space of container for leaching). Soluble fertilizer was injected into the irrigation water with each irrigation at the rate of 50 mg $N \cdot L^{-1}$ (50 ppm N), 20N-8.6P-16.6K (20-20-20).

Stomatal conductance (g_s) of 8 plants from each irrigation and shade level was measured twice weekly, on Tuesday and Thursday, at 1400 CST with a steady-state porometer (Model 1600, LiCor, Inc., Lincoln, NE). One leaf (usually the second or third morphologically mature leaf) was measured from each plant using the abaxial surface. Only the abaxial (lower) surface was measured [most woody shrubs are hypostomatous, which means that the majority of the stomata are on the abaxial or lower leaf surface (5)]. The g_s weekly values were pooled and reported as biweekly to remove variability. The data for g_s, and shoot were analyzed as a modified split plot repeated measures design (the whole plot was shading, but was not tested in the model as a main effect because it was not truly replicated).

Predawn Ψ_{shoot} of 40 selected plants from each irrigation and shade level was measured with a pressure chamber (Plant Water Status Console, Model 3000, Soilmoisture Equipment Corp., Santa Barbara, CA) according to Rudich, et al. (10) and Scholander, et al. (11). Half of these plants were measured during the odd weeks and the remaining half were measured during the even weeks. This prevented excessive damage to the plants. The weekly Ψ_{shoot} values were pooled and reported as biweekly measurements to remove variability. None of the plants used for gs were used for shoot. The g_s and Ψ_{shoot} were measured for 16 weeks between May 15, 1986 and September 12, 1986.

Plant growth analysis included leaf area and plant dry weight measured only on the plants used for g_s. Leaf chlorophyll was measured on plants used for Ψ_{shoot} measurements. Leaf area was measured with a leaf area meter (LiCor Models 3000 and 3050A, LiCor, Inc., Lincoln, NE). Root and shoot dry weights were measured after drying leaves, stems, and washed roots in a convection oven at 60°C (140°F) for 48 hr. Plant dry weight was the total weight of the leaves, stems, and roots. Chlorophyll content was measured according to Arnon (2). The plant growth data were analyzed as a modified split plot design (the whole plot was shading, but was not tested in the model as a main effect because it was not truly replicated).

Results and Discussion

Water relations. Stomatal conductance (g_s) was affected by the two-way interactions of shading and week of study, and irrigation frequency and week of study, but not the two-way interaction of shading and irrigation or the three-way interaction of shading, irrigation frequency and week of study (by analysis of variance, $\alpha < 0.05$). Stomatal conductance (g_s) is a measure of the amount of stomatal opening of a leaf surface measured by the amount of moisture leaving the leaf. As plants become water stressed, the stomata close and the g_s is reduced. With a reduction in g_s, CO_2 uptake and resulting photosynthesis is reduced. Well watered plants have high g_s values indicating water transport from the leaf to the atmosphere.

Predawn Ψ_{shoot} was affected by the three-way interaction of the effects shade, irrigation frequency, and week of study (by analysis of variance, $\alpha < 0.05$). Shoot water potential is a meausre of the degree of water deficit of a leaf. Water moves along water potential gradients, from regions of higher energy (such as a well-watered root-zone) to those of low energy (such as a leaf surface and ultimately the atmosphere). These energy levels are expressed in terms of negative pressure, usually bars or MPa (mega Pascals). As a plant begins to become water stressed (losing more water than it is taking up), the water potential (Ψ_{shoot}) becomes lower (more negative) and becomes less turgid. Well-watered plants, that are actively transporting water, have open stomata and higher (less negative) Ψ_{shoot} values and are turgid.

Irrigation 3 times per week reduced g_s of plants compared to irrigation daily and twice daily during weeks 8 through 14 for plants produced under shade and during weeks 4 through 12 for plants produced under full sun (Table 1). No differences in gs were detected between shading levels at each irrigation frequency (Table 1).

Few differences were detected in Ψ_{shoot} under shade at any irrigation level (Table 2). The Ψ_{shoot} was reduced for plants under full sun and irrigated 3 times per week compared to irrigation daily and twice daily during week 10 and remained lower for the remainder of the study.

Plant growth. Plant dry weight, leaf area, and root dry weight were affected by the two-way interaction of shading and irrigation frequency (by analysis of variance, $\alpha < 0.05$). Plant dry weight and leaf area were greatest when plants were grown under shade and watered once daily compared to twice daily and 3 times per week (Table 3). No differences in plant dry weight or leaf area were detected between irrigation levels for plants grown under full sun. All plants grown under shade were greater in both dry weight and leaf area than those grown under full sun (Table 3).

No differences were detected in root dry weight between any of the irrigation rates for plants grown under shade or full sun (Table 3). All plants grown under shade had a greater root mass than those grown under full sun (Table 3).

Chlorophyll analysis. Leaf chlorophyll was determined and expressed per unit leaf area. The two-way interaction of the treatments shading and irrigation frequency affected leaf chlorophyll (by analysis of variance, $\alpha < 0.05$). Chlorophyll of plants grown in full sun was not influenced by irrigation (Table 3). Plants irrigated twice daily and grown under shade had more chlorophyll per unit leaf area compared to irrigated once daily and were similar to plants irrigated 3 times weekly. Chlorophyll levels of plants irrigated once daily were also similar to plants irrigated 3 times weekly. Plants grown under shade had 127% more chlorophyll per unit leaf area than plants in full sun on the average (Table 3).

This study indicated that *E. japonica* plants, under southeastern U.S. nursery conditions, grew best under shade when irrigated once daily. This treatment resulted in plants with the highest plant dry weight and leaf area. Shade plants that were irrigated twice daily had the highest level of chlorophyll per unit area, however, because this cultivar of *E. japonica* was variegated, these plants were perhaps excessively green and not as marketable. The low chlorophyll levels in the full sun plants indicated that the leaves were bleached from excessive sun or had limited nutrient and

Table 1. Effects of weeks into study, irrigation frequency, and shade on predawn shoot water stomatal conductance of *Euonymus japonica* 'Aureo-marginata'.

Irrigation	Weeks 2	4	6	8	10	12	14	16
	(cm·sec^{-1})							
	Shade							
1×/day	0.41a[z]	0.54a	0.63ab	0.60a	0.55a	0.64a	0.64a	0.68a
2×/day	0.33a	0.51a	0.70a	0.58a	0.63a	0.62a	0.57a	0.68a
3×/day	0.34a	0.56a	0.60b	0.46b	0.19a	0.46a	0.48b	0.64a
	Full Sun							
1×/day	0.38a	0.61a	0.59a	0.60a	0.57a	0.59a	0.65a	0.68a
2×/day	0.38a	0.58a	0.57a	0.56a	0.48a	0.49b	0.47b	0.55b
3×/day	0.31a	0.48b	0.46b	0.46b	0.19b	0.21b	0.38b	0.52ab

[z]Mean separation within columns and irrigation frequency by least significant difference ($\alpha < 0.05$).

Table 2. Effects of weeks into study, irrigation frequency, and shade on predawn shoot water potential of *Euonymus japonica* 'Aureo-marginata'.

Irrigation	Weeks 2	4	6	8	10	12	14	16
	(MPa)							
	Shade							
1×/day	−0.12a[z]	−0.17a	−0.24a	−0.39a	−0.33a	−0.40b	−0.30ab	−0.14a
2×/day	−0.12a	−0.15a	−0.23a	−0.32a	−0.29a	−0.35a	−0.29a	−0.15a
3×/day	−0.13a	−0.12a	−0.21a	−0.33a	−0.38a	−0.41b	−0.33b	−0.16a
	Full Sun							
1×/day	−0.14a	−0.13a	−0.25a	−0.29a	−0.31a	−0.42a	−0.37a	−0.19a
2×/day	−0.13a	−0.13a	−0.24a	−0.31a	−0.32a	−0.42b	−0.34a	−0.19a
3×/day	−0.11a	−0.11a	−0.24a	−0.31a	−0.46b	−0.71b	−0.53b	−0.25b

[z]Mean separation within columns and irrigation frequency by least significant difference ($\alpha < 0.05$).

Table 3. Effects of irrigation frequency and shade on plant dry weight, leaf area, root dry weight, and leaf chlorophyll of *Euonymus japonica* 'Aureo-marginata'.

Irrigation	Plant Dry Weight		Leaf Area		Root Dry Weight		Leaf Chlorophyll	
	Shade	Full Sun	Shade	Full Sun	Shade	Full Sun	Shade	Full Sun
	(g)		(dm^2)		(g)		($mg \cdot cm^{-2}$)	
1×/day	34.4a[z]	8.2a	18.7a	3.5a	3.43a	1.56a	7.64b	6.55a
2×/day	24.6b	12.1a	13.4b	6.2a	2.80a	2.03a	8.33a	6.13a
3×/week	21.0b	9.2a	12.9b	3.4a	2.62a	2.63a	8.12ab	6.60a

[z]Mean separation within columns by least significant difference ($\alpha < 0.05$).

water uptake due to high root-zone temperatures (8). Kappel and Flore (7) reported that leaf area and chlorophyll per unit leaf area were increased with shading. No differences between shade levels for specific leaf area was observed in our study that would have confirmed observations for young peach trees reported by Kappel and Flore (7).

Shade grown plants had larger root systems than plants grown in the full sun; however, the shade grown plants had smaller root/shoot ratios (shoot dry weight/root dry weight, data not shown) indicating that these plants had a smaller root system in relation to its shoot system. Often woody plant growers observe a visually acceptable plant when shade grown, however, the root system will be limited and stored food resources will be inadequate to support any stress encountered, whether environmental, diseases, or pests (13). Shade grown plants should not be abruptly moved to an area of high light intensity or potential water stress without acclimation.

Plants were not under any attributable water stress when grown under shade at any irrigation level as indicated by Ψ_{shoot}. However, plants grown under shade and irrigated 3 times weekly had lower g_s compared to once or twice daily irrigation during the weeks 8 through 14. During this period, the relative humidity was less than 85% and the average leaf temperature of the plants irrigated 3 times weekly was 35.5°C (95.9°F) resulting in a vapor pressure deficit of 2.6 kPa (kiloPascals), a high evaporative demand that was not being fully met by available moisture (3, 10, 12). This was supported by lower predawn Ψ_{shoot} during weeks 12 and 14 for plants grown under shade and irrigated 3 times weekly. Vapor pressure deficit is a measure of the difference between the vapor pressure within a leaf (based on leaf temperature and the relative humidity of the intercellular spaces within a leaf) and the vapor pressure of the atmosphere (based on the air temperature and the relative humidity). When a leaf becomes water stressed, the stomata close lowering conductance, the water potential becomes lower, and ultimately the leaf temperature increases (less transpiration, less evaporative cooling). These changes increase vapor pressure deficits compounding water stress.

The water relations data does indicate that plants grown under full sun were under water stress when irrigated 3 times weekly. Few differences were detected during the early weeks of the study primarily due to a period of high humidity and rainy weather (12), but after week 6, treatment differences became more pronounced. From week 6 through the termination of the experiment, g_s was reduced on plants irrigated 3 times weekly. During this period, the relative humidity was less than 89% and the average leaf temperature of the plants irrigated 3 times weekly was 35.3°C (95.5°F) resulting in a vapor pressure deficit of 2.7 kPa, as with shade plants, a high evaporative demand existed that was not being fully met by available moisture (3, 10, 12). Predawn Ψ_{shoot} of plants grown under full sun and irrigated 3 times weekly began to decrease after 10 weeks, lagging behind the drop in g_s by 4 weeks.

Predawn Ψ_{shoot} during weeks 10 through 16 for plants grown under full sun and irrigated 3 times weekly was reduced to levels less than −1 MPa (−10 bars). Mid-day Ψ_{shoot} was not measured, but during this period the maximum temperatures exceeded 40°C (104°F) and the minimum temperatures (predawn) were 19°C (34°F) lower or less than the average maximum daily temperature. These environmental factors resulted in conditions that depleted plant moisture to a level that the media water was not able to provide during the night, thus the predawn Ψ_{shoot} decreased. Atmospheric factors tend to affect Ψ_{leaf} more during daylight hours than soil water availability (12). The average daily maximum temperatures in the shade rarely exceeded 40°C (104°F) and the minimum temperatures remained higher than those not under the shade which seemed to hold some heat through the night. Consequently, these plants were not under a great a transpirational strain and maintained a better water status than those under full sun with a limited water supply.

A broad interpretation of the water relations data indicated that there was no added benefit from the twice daily irrigation treatment compared to once daily, whether under full sun or shade. However, plant dry weight and leaf area of plants grown under shade were reduced by irrigation twice daily to a level similar to irrigation 3 times weekly. Therefore, excess irrigation lead to reduced plant growth perhaps due to anoxia, lack of oxygen, in the root-zone (1). Irrigation twice daily did increase plant quality of plants grown under full sun compared to once daily and 3 times weekly, but the increase was considerably less than all plants under shade and the plants were not of marketable quality.

Significance to the Nursery Industry

This study demonstrates that *E. japonica* container production in the southeast is limited to shade and that plant quality and growth is reduced with over watering. The highest quality and most marketable plants were shade grown and trickle irrigated once daily. Excess water, in addition to reduced plant growth, reduced the intensity of variegation of the foliage making them less desirable.

Literature Cited

1. Anderson, P.C., P.B. Lombard, and M.N. Westwood. 1984. Leaf conductance, growth, and survival of willow and deciduous fruit tree species under flooded soil conditions. J. Amer. Soc. Hort. Sci. 109:132–138.

2. Arnon, D.L. 1949. Copper enzymes in isolated chloroplasts: Polyphenoloxidase in *Beta vulgaris*. Plant Physiol. 24:1–15.

3. Baldocchi, D.D., S.B. Verma, N.J. Rosenberg, B.L. Blad, A. Garay, and J.E. Specht. 1983. Influence of water stress on the diurnal exchange of mass and energy between the atmosphere and a soybean canopy. Agron. J. 75:543–548.

4. Davidson, H., R. Mecklenberg, and C. Peterson. 1987. Nursery Management: Administration and Culture, 2nd ed. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

5. Hsiao, T.C. and R.A. Fischer. 1975. Resistance measurements: Mass flow porometers, *In*: Measurement of stomatal aperture and diffusive resistance. Washington State University Bull. 809.

6. Ingram, D.L. 1981. Characterization of temperature fluctuations and woody plant growth in white polybags and conventional black containers. HortScience. 16:762–763.

7. Kappel, F. and J.A. Flore. 1983. Effect of shade on photosynthesis, specific leaf weight, leaf chlorophyll content, and morphology of young peach trees. J. Amer. Soc. Hort. Sci. 108:541–544.

8. Newman, S.E. 1985. Effects of mycorrhizal fungi on high temperature root stress of container-grown nursery crops. PhD Diss., Texas A&M Univ., College Station, TX.

9. Newman, S.E. and F.T. Davies, Jr. 1988. High root-zone temperatures, mycorrhizal fungi, water relations, and root hydraulic conductivity of container-grown woody plants. J. Amer. Soc. Hort. Sci. 113:138–146.

10. Rudich, J., E. Rendon-Poblete, M.A. Stevens, A.I. Ambir. 1981. Use of leaf water potential to determine water stress in field-grown tomato plants. J. Amer. Soc. Hort. Sci. 106:732–736.

11. Scholander, P.F., H.T. Hammel, E.D. Bradstreet, and E.A. Hemingson. 1965. Sap pressure in vascular plants. Science. 148:339–346.

12. Stanley, C.D., B.K. Harbaugh, and J.F. Price. 1983. Environmental factors influencing leaf water potential of chrysanthemum. J. Amer. Sco. Hort. Sci. 108:237–240.

13. Whitcomb, C.E. 1984. Plant Production in Containers. Lacebark Publications, Stillwater, Oklahoma.

14. Whitcomb, C.E. 1981. Controlling the temperatures in containers, *In*: Nursery Research Field Day. Research Report P-818, Agr. Expt. Sta., Oklahoma State Univ.